ANALYSIS ON MECHANICAL BEHAVIOUR AND STABILITY OF STIFF SKELETON ARCH RIB WITH LONG SPAN DURING CONSTRUCTION PHASE

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SUMMARY

The main bridge of Youxi Bridge which lies in Xiangpu railway is a X-style stiff skeleton reinforced concrete arch bridge, the arch rib is strong across ability by its great structural rigidity, but the arch rib forming process system variable, with complex mechanical behaviour. To study the mechanical behaviour and the stability of the stiff skeleton concrete arch rib, the spatial finite element model with solid and beam elements was established to simulate the construction processes of the concrete-filled steel tube sections and concrete box sections. The calculation result shows: the concrete filled in steel tube pouring sequence do little effects on the steel tube stresses, program of casting concrete arch outsourcing have a great impact on the concrete stresses, tensile stress of concrete does not appear during the construction process with tricycle casting concrete arch outsourcing program used in this bridge, during the actual construction, casting concrete arch outsourcing for each section in every layer concrete should be simultaneous, to make the actual construction agree well with the calculation model. The stability factors in the construction process are all greater than 4 which can meet the requirements in the relevant codes. The analysis results can provides the references for the same kind of bridge design and construction.

Keywords: *Stiff skeleton concrete arch rib, construction phase, mechanical behaviour, stability.*

1. INTRODUCTION

In recent twenty years, concrete-filled steel tubular stiffening framework arch bridge has got rapid development in China, which uses concrete-filled steel tube as stiffening framework, and then use it as a construction scaffold, erecting templates on it to cast concrete segmented and layered, then form a concrete stiffening framework arch rib. This structure makes full use of steel and concrete, overcomes the construction difficulty caused by excessive weight of ordinary concrete arch rib, saves brackets, makes construction easy, and the rigidity of the structure is big, has strong spanning ability, has very obvious advantages applied to large span and heavy structures, can well be applied to canyon and valley with better geological conditions, there are many successful precedents in the construction of highway and railway Bridges at home and abroad [1-3].

However, the structural mechanics model, the loading method and some basic parameters are changing all the time in stiffening framework arch rib construction process, has the characteristics of time-varying structure, especially in the formation of concrete-filled steel tube cross section and the reinforced concrete box section, the stress and stability has always been a matter which engineering person pay special attention to [4-9].

Youxi bridge of Xiangpu railway is a deck type reinforced concrete arch bridge, in order to study internal force and stability of the concrete-filled steel tubular stiffening framework arch rib during construction ,the spatial structure model is established in this paper which contains solid element, beam element and truss element, simulating the establishment of the concrete filled steel tube cross section and the reinforced concrete box section, then make a comprehensive evaluation on the safety of the structure, and provide reference for similar design and construction of arch bridge.

Fig. 1. *Youxi bridge photo.*

2. PROJECT PROFILE

Youxi bridge of Xiangpu railway is located in Fujian province, China, crossing the navigable Youxi river ,the terrain of bridge site is steep, which is V shape valley, most of the bedrock on both sides is exposed, geological conditions are good, which are very suitable for building deck type arch bridge structure that is in harmony with the environment. For Railway Bridge bearing large live load and high stiffness of the structure is demanded, the deck type stiffening framework reinforced concrete arch bridge is adopted in the bridge design. As shown in figure 1,the main bridge is I-140 m double railway deck type stiffening framework reinforced concrete arch bridge, the arch rib is X type stiffening framework reinforced concrete arch, the arch axis is catenary, the arch axis coefficient is 2.514, the rise-span ratio is 1/4.516 (plane vector height is 30.864 m), the dip angle is 5.37. Arch rib steel framework is welded into a stiffening framework with 8 ϕ 402×14 mm (ϕ 402x20 mm) seamless steel tubes and the gusset plate、angle steel. After hoisting and closing steel framework by tower crane, steel tube filled with C55 micro expansion concrete is used as arch rib concrete construction scaffold, stiffening framework reinforced concrete is formed after the construction of outside concrete. There are 11 cross-braces in arch rib of the whole bridge, the brace is welded by steel tube and angle steel, then pouring outside concrete.

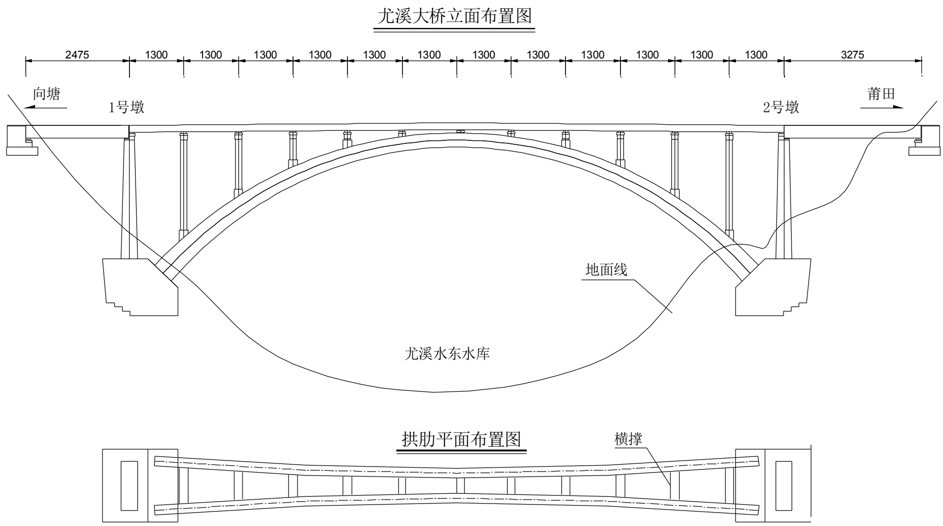


Fig. 2. Arrangement of Youxi bridge.

3. ANALYSIS AND CALCULATION OF INTERNAL FORCES DURING CONSTRUCTION

3.1. The construction sequence and calculation model

The arch rib construction order is: Firstly, hoist and erect the steel tube frame by the crane ;after the closure of steel frame, first pour concrete into the top chord steel tube, then pour concrete into the lower chord steel tube, pour stiffening framework outside concrete by dividing six sides and three rings after the concrete meets the design strength, as shown in Fig. 3. The formation of the arch rib should pass a series of system conversion, according to the construction sequence, there are four states ,the steel framework, concrete-filled steel tube stiffening framework, stiffening framework with partial outside concrete and concrete-filled steel tube arch rib. According to the mechanical characteristics, the forming process of arch rib can be divided into the following three calculation model: (1) steel framework is simulated as a truss model; (2) it is concrete-filled steel tube model after pouring concrete into steel frame and meeting the design strength; (3) stiffening framework reinforced concrete is formed when concrete filled steel tube stiffening framework is packaged by outer-packed concrete.

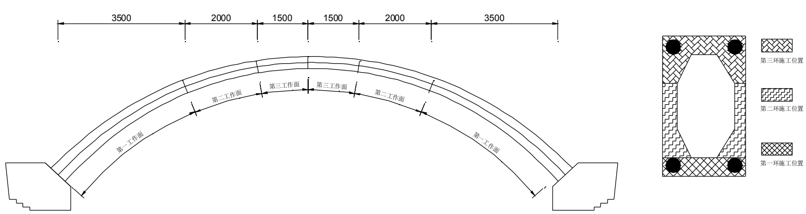


Fig. 3. Schematic Diagram of Main Cast Concrete Arch Outsourcing.

Calculation model of construction process can be established according to the above methods, as shown in Fig. 4. The upper chord elements of arch timbering are 1~78; the lower chord elements of arch timbering are101~178; the concrete elements in the upper chord tube are 601~678; the concrete elements in the lower chord tube are 1101~1178. The arch rib outside concrete is poured with three times. the nodes of the element are 201~279 (located in the arch axis), the stiffness value is taken according to the actual stiffness and make rigid connection with stiffening framework, the elements number as follows: the first ring outer-packed concrete are 2201~2274, the second ring outer-packed concrete are 2401~2474, the third ring outer-packed concrete are 2601~2674; the temporary support assembled of the first segment steel frame is simulated by gapless press element. Temporary cable in the process of steel tube frame cantilever is simulated by cable element, the stiffness values of 1 # and 2 # pier, columns on the arch and girder are taken according to the actual values, calculation model is the whole bridge model, horizontal linkages are calculated as concentrated force on the corresponding node of the model. Because of space constraints, this paper only gives the half bridge element division of stiffening framework concrete poured in the last ring. It is needed to note that the steel tube stiffness value of each ring outer-packed concrete element is determined by section rigidity difference which is formed after two ring pouring at a time.

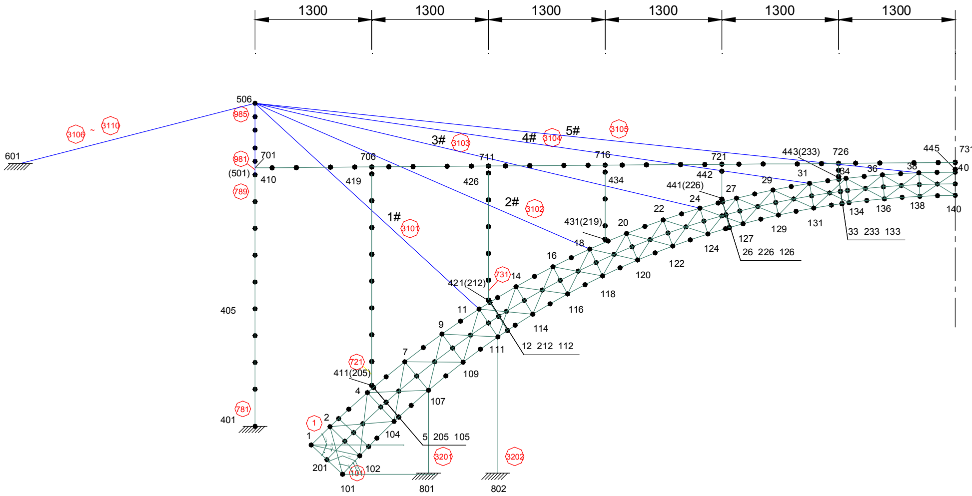
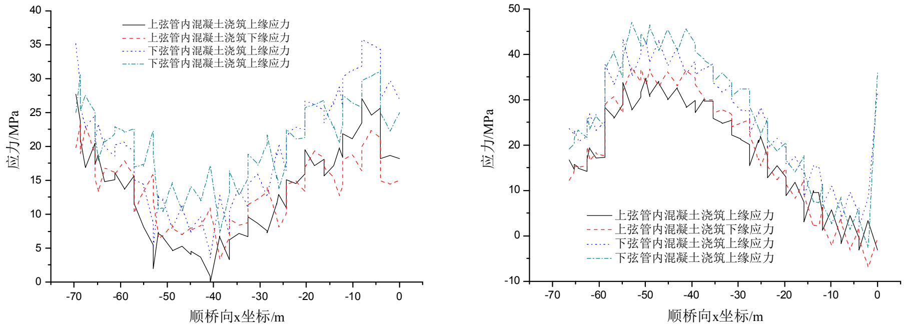


Fig. 4. *Schematic diagram of main cast concrete arch outsourcing.*

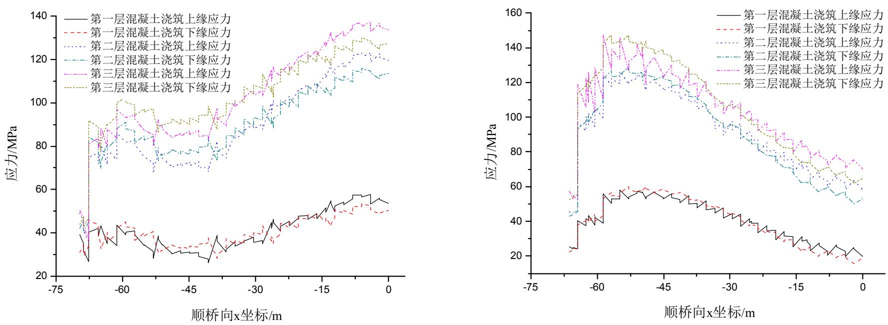
3.2. Calculation results and analysis

Modelling and calculation are based on above analysis model ,force situation of steel tube stiffening framework and outer-packed concrete can be obtained in the construction of steel tube arch rib, due to space limitations. this article only lists the typical phases of calculation results, thereunto, the stress of steel tube frame is shown in Fig. 5~6, the stress of layered outer-packed concrete is shown in Fig. 7~8, the picture shows a half span stress situation, compressive stress is positive, tensile stress is negative.



a) stress of upper chord *b) stress of lower chord*

Fig. 5. *Steel Tube Stress of Pouring Concrete.*



a) stress of upper chord *b) stress of lower chord*

Fig. 6. *Steel Tube stress of Casting Concrete Arch Outsourcing.*

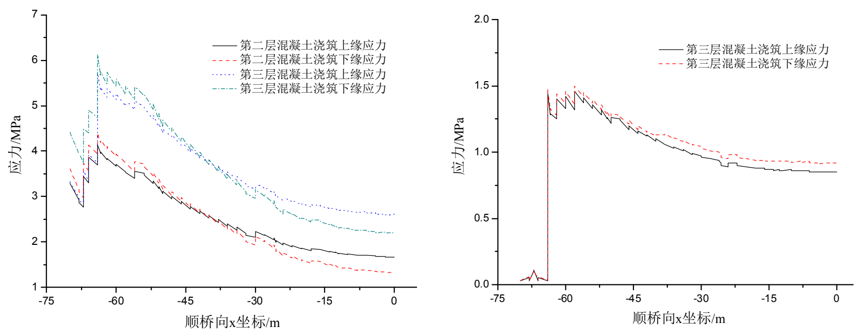


Fig. 7. *First layer concrete stresses of Concrete Arch Outsourcing on the left, on the right: Second layer concrete stresses of Casting Casting Concrete Arch Outsourcing.*

From the Fig. 5 calculation result, first pouring the upper chord tube concrete and then pouring the lower chord tube concrete, the maximum and minimum (tensile, pressure) stress values of the upper chord tube is close to the lower chord tube, the construction scheme is feasible. Analysis and comparison of the original scheme that pouring lower chord tube concrete after pouring the upper chord tube concrete, it can be found a different order pouring tube concrete has little effect on the stress of the upper and lower chord of the stiffening framework, from the stress state of the whole chord, the construction scheme of first pouring the lower chord tube concrete is slightly better. As can be seen from the Fig. 5, the maximum stress of upper and lower chord tube is controlled in less than 150 MPa, the scheme of outsourcing concrete is feasible, but the increase of steel tube stress is larger after pouring the second ring concrete ,this is because more concrete is poured in the second ring. As can be seen from the Fig. 6~7, the pouring of the arch rib outer-packed concrete is divide into three rings, the stress of the concrete poured in the first and second ring are compressive stress, the construction project is feasible. Analysis and comparison of the original four rings scheme ,it can be found that tensile stress appears in the first layer of concrete during the whole process of pouring outer-packed concrete, three-ring pouring scheme has improved the mechanical situation of the outer-packed concrete. It is worth pointing out that the pouring weight of each layer concrete is simulated by virtual element (only weight, infinitesimal stiffness), which is added once at the same time in the calculation and analysis, therefore, it is ensured that stage concrete of each layer is poured at the same time in the actual construction, making the actual construction in accordance with the calculation model as far as possible.

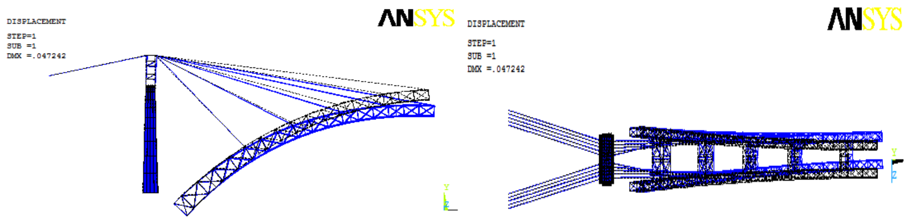
4. STABILITY ANALYSIS OF STEEL FRAME CONSTRUCTION

Stability of stiffening framework in the process of construction is very important to assure the safety in construction [10,11], so the stability of arch rib structure must be calculated to guide the construction of the bridge .the space model is established by the general finite element software ANSYS in this paper [12], linear elastic stability in construction stage of Youxi Bridge is analysed according to the related specification and engineering experience, considering the structure stiffness increases greatly after the formation of concrete filled steel tube stiffening framework, therefore, the stability of two key construction stage is mainly analysed, (1) the maximum cantilever construction stage of the steel tube frame; (2) the construction stage of pouring tube concrete after the steel frame closure. It is considered that the horizontal wind cable only plays the role of adjusting the arch axis, which has little effect on the structure ,so do not thinking about it.

4.1. Steel frame stability of maximum cantilever construction stage

In the finite element model, pier adopts SOLID45 element ,temporary cable adopts LINK10 element ,steel tube frame and temporary tower adopts BEAM188 three-dimensional beam element to simulate, anchor and arch foot adopt hinged constraint, load are the weight of steel tube frame、cable force and horizontal wind load. The construction live load is converted into concentrated force applied to the each nodes, the wind load is calculated according to the railway bridge basic specifications, the maximum wind speed adopts V=25 m/s in construction of main bridge, the incremental load method is adopted in the analysis in each construction stage, influence on stability of subsequent constructed steel frame, which is caused by the first part of steel tube frame closure pouring concrete and considered by applying initial stress on the first part of the construction element.

Calculation results are shown in Fig. 9, the construction phase instability patterns is the out of plane symmetric instability, the first order buckling stability coefficient is 32.9, meeting the specifications which requires the stability coefficient is greater than 4~5, global stability of the structure has a big surplus.



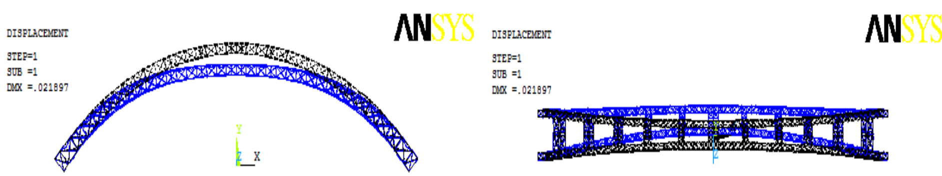
a) front view *b) planform*

Fig. 9. *First order instability mode of steel tube skeleton maximum cantilever assembled stage.*

4.2. Stability of concrete filled in steel tube skeleton stage after the closure

Element type of the finite element model is in accordance with the stability analysis of the steel tube skeleton maximum cantilever construction stage, according to the construction procedure, the temporary pestle cable of the construction phase has been removed, the load are the weight of steel skeleton, concrete weight and horizontal wind load, the loading method is element uniform load.

The calculation results are shown in figure 10, the construction phase instability pattern is the out-of-plane symmetric instability, the first order buckling stability coefficient is 19.1, meeting the specifications which requires the stability coefficient is greater than 4~5 and requirements of structure stability.



a) front view *b) planform*

Fig. 10. *First order instability mode of concrete filled in steel tube skeleton stage.*

5. CONCLUSIONS

Stress state and stability coefficient of stiffening framework under different working conditions are got based on the calculation and analysis of stress states. And structure stability during the construction .it is ensured that stage concrete of each layer is poured at the same time in the actual construction, making the actual construction in accordance with the calculation model as far as possible.

The order of pouring concrete into chord steel tube has little effect on the chord stress , the layered pouring scheme of arch rib outer-packed concrete has great influence on stress of concrete, The bridge does not appear tensile stress in pouring outer-packed concrete using the three-ring project ,arch rib concrete is in compression state during the whole construction.

Concrete filled steel tube stiffening framework arch rib three-dimensional calculation model is established in stability analysis, the results show that steel tube arch frame largest cantilever stage first order buckling stability coefficient is 34.3, the first order buckling stability coefficient is 19.1 after pouring concrete into the chord steel tube, stability coefficient is greater than 4 in the process of construction, meeting the requirements of specification, and the stability of the global structure has a larger safety stock.

REFERENCES

[1] CHEN Baochun, Concrete filled steel tube arch bridge, Beijing: China Communications Press, 2007.

[2] FENG Chuqiao, PAN Maosheng, The main design of the Diao zhong yan large bridge of Ganlong railway, *Railway Standard Design*, No. 11, 2005, pp. 79-82.

[3] QU Guozhao, LIU Huaquan, 178 m Luobuxi concrete arch bridge design of Yiwang railway. *Railway Standard Design*, No. 11, 2005, pp. 57-59.

[4] ZHANG Zhicheng, Simulation analysis for mechanic behaviour of concrete-filled steel tubular arch bridge during the course of core concrete pumping, *Engineering Mechanics*, Vol. 24, No. 2, 2007, pp. 146-153.

[5] YANG Bingcheng, WU Gangrong, LIU Jian, Nonlinear analysis of long span arch bridges reinforced with concrete-filled steel tubes, *Bridge Construction*, No. 1, 2006, pp. 5-7, 15.

[6] ZHANG Ben, The construction optimization design of the long-span rigid frame concrete box arch bridge, Chongqing: Chongqing Jiaotong University, 2011.

[7] WANG Feng, WANG Pingli, Analysis on mechanical behaviour of SRC arch Bridge with large span concerning process of construction, *Railway Survey*, No. 1, 2010, pp. 95-98.

[8] LIU Jian, Research on main arch ring construction scheme of long span concrete-filled steel tube rigid frame arch bridge, Xi'an: Chang'an University, 2007

[9] Qu Lin, SUN Jibiao, Analysis on stability of concrete filled steel tube arch bridge in construction, *Journal of Chongqing Jiaotong University (natural science)*, Vol. 27, No. 3, 2008, pp. 366-369.

[10] XIE Shangying, QIAN Dongsheng, Non-linear stability analysis of concrete arch bridge with stiff skeleton of concrete-filled steel tubes during construction, *China Civil Engineering Journal*, Vol. 33, No. 1, 2000, pp. 23-26.

[11] ZHAO Lei, DU Zhenguo. Analysis of Stability During Construction of the Steel-Tube Concrete Stiff Skeleton of Long-Span RC Arch Bridge, *Journal of southwest Jiao tong university*, Vol. 29, No. 4, 1999, pp. 446-452.

[12] YAN Donghuang, LAI Minzhi, ZHANG Kebo et al, Space calculation model of Maocaojie Bridge based on the ANSYS, *Journal of Changsha Communication University*, Vol. 19, No. 2, 2003, pp. 6-10.